ANALYSIS OF WDM NETWORK BASED ON EDFA PUMPING AND DISPERSION COMPENSATION USING OPTISYSTEM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT

OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Communication and Signal Processing

by

SUSHANTA KUMAR SWAIN

Roll No: 210EC4318

Department of Electronics & Communication Engineering

National Institute of Technology

Rourkela

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Under the guidance of

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CERTIFICATE

This is to certify that the thesis entitled, "**ANALYSIS OF WDM NETWORK BASED ON EDFA PUMPING AND DISPERSION COMPENSATION USING OPTISYSTEM**" submitted by SUSHANTA KUMAR SWAIN in partial fulfillment of the requirements for the award of Master of Technology degree in **Electronics and Communication Engineering** with specialization in "**Communication and Signal Processing**" during session 2011-2012 at National Institute of Technology, Rourkela (Deemed University) and is an authentic work by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/institute for the award of any Degree or Diploma.

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CONTENTS

ABSTRACT

In WDM networks optical fibres are employed to transmit information in form of light pulse between the transmitter and the receiver. WDM systems have the potential to transmit multiple signals simultaneously. But the light signals degrade in intensity when they travel a long distance inside the fibre. So it is required to amplify all the light signals simultaneously after a certain interval of light propagation to regain the original signal. Optical amplifiers are generally used to amplify the light pulses. There are many optical amplifiers are used. One of the common amplifiers used is Erbium Doped Fibre Amplifier.

In this thesis the analysis of WDM network is done on the basis of EDF amplification and dispersion compensation mechanism using optisystem software. In WDM networks optical fibres are used and they suffer from heavy loss due to attenuation and dispersion. So in order to reduce these attenuation losses optical amplifiers are used. Here first the gain and noise figure of the EDFA with different pumping techniques is analysed and is observed that forward pumping shows the best noise figure and backward pumping technique shows highest gain value. In case of Bi-directional pumping we get good gain and noise figure value. WDM networks also suffer from dispersion and to compensate this dispersion in fibre DCF is used. So finally the dispersion effect on the WDM network is analysed with different SMF and DCF length at different data rate of 10Gbps and 40Gbps for 8 channels, 16 channels and WDM network for different amplifier spacing. It is observed that 10Gbps bit rate network shows better Q-Factor than 40Gbps data rate WDM network.

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ACRONYMS

EDFA- Erbium Doped Fibre Amplifier

WDM - Wavelength Division Multiplexing

BER - Bit Error Rate

Q-Factor - Quality Factor

SMF – Single Mode Fibre

DCF – Dispersion Compensating Fibre

SOA – Semiconductor Optical amplifier

SNR – Signal to Noise Ratio

NF – Noise Figure

NRZ- Non Return-to-Zero

RZ - Return to Zero

Chapter 1

Introduction

1.1 Goal and Motivation

1.1.1 Goal

The goal of this thesis is to analyse the optical amplifiers and dispersion compensating fibres and optimizing their performance for a wavelength division multiplexing network. The optical amplifier behaviour is studied at different parameters and their results are optimized for better performance. The dispersion compensating fibres and their use in WDM optical network is verified.

1.1.2 Motivation

WDM optical networks are the revolution in data transmission because of low loss, high speed, better bandwidth and high capacity. So a lot of research is going on in this field. Optical amplifiers are the backbone of optical network as they amplify the signal which occurs due to the fibre losses and many other reasons. EDFA is the optical amplifier which is the most used amplifier because of their high gain and low pump power. So EDFA behaviour in a WDM network needs to be studied. So in this project EDFA gain and noise figure at different pumping wavelength is analysed.

Fibres also suffer from dispersion due to fibre material nonlinearities and distance the signal travels inside the fibre. So this dispersion has to be minimised by some methods. Installing the DCF fibres is one of the methods to compensate the dispersion due to single mode fibres. The DCF are analysed with various data rate and configurations for defining the optimum results.

1.1 Literature Survey

M. Pal, M.C. Paul, A. Dhar, A. Pal, R. Sen, K. dasgupta and S.K. Bhadra [7] compared the EDFA gain and noise figure for various pumping schemes for 16 channel transmitter. Here a brief description of the pumping techniques is shown and comparison of the pumping techniques is done.

R. Kaler and R.S. Kaler [8] describe the gain and noise figure for EDFA and compact EDFA.

A. Malekmohammadi and M.A. Malek [9] shows the EDFA gain optimization for 32X10 Gbps WDM systems. In this paper how to optimize the gain for 32 channel WDM system with data rate of 10Gbps is shown.

R. Deepa and R. Vijaya [10] gave the idea of influence of bidirectional pumping for high power EDFA for single channel and multi-channel WDM system. Here we get a good idea of the bidirectional pumping scheme.

P. Schiopu and F. Vasile [11] EDFA performance is analysed. In this paper the gain is investigated with various pumping power. From this paper pumping power required for EDFA can be investigated.

S Milo, R.F. Souza, M.B.C. Silva, E. Conforti and C. Bordonalli [13] shows the theoretical analysis of different configuration and pumping wavelength.

G. Yan, Z. Ruixia, D. Weifeng, and C. Xiaorong [19] gives the idea to create a WDM network using optisystem. It also shows the SMF and DCF dispersion values. We get a good idea of creating a 32X40 Gbps network using optisystem.

1.3 Objective

1. To study and investigate the gain and noise figure of an EDFA at different pumping techniques and different pumping wavelengths and power. The different pumping techniques are copumping, counter pumping and bidirectional pumping.

2. To analyse dispersion compensation with DCF for 8-channel and 16-channel WDM network at 10Gbps and 40Gbps data rate. Here the Q-factor and BER of the different configurations will be compared.

1.4 Thesis Overview

This thesis consists of five chapters that contain introduction, working of the system, results and discussion for each chapter.

Chapter 2: Optical Fibre communication, which contains brief introduction of the optical fibre communication system, its advantage, WDM networks and Optical amplifiers.

Chapter 3: Analysis of gain and noise figure for EDFA with different pumping techniques. Here in the introduction various pumping techniques are discussed. And in the result section gain and noise figure is investigated.

Chapter 4: Effect of Dispersion compensating fibres at high bit rate. Here for 8-channel and 16-channel WDM network the Q-factor and BER is shown at different data rate of 10Gbps and 40Gbps in the presence of DCF module.

Chapter 5: Conclusions, gives the conclusions drawn from the above chapters in this paper. And Future development describes possible continuation of this work.

Chapter 2

Optical Fibre Communication

Introduction

Communication is transmission of information from one place to another through one medium. Mankind has been using many mediums for the data transmission. One of these mediums that really had a big impact on data transmission was coaxial-cable system. The first coaxial-cable system, deployed in 1940 [2], was a 3MHz system which could transmit 300 voice channels. But these coaxial-cables, they mostly suffer from high cable losses and repeater spacing is also very limited and is costly for a longer transmission length. And these shortcomings led to the development of microwave communication system. Microwave communication system uses electromagnetic carrier waves in the range of GHz to transmit signals with different techniques to modulate the carrier waves. The microwave communication system allowed larger repeater spacing but suffered from limited bit rate. Then Optical fibre was first developed in the 1970s, which revolutionized the telecommunications industry and played a major role in the Information era. Because of its advantages over electrical transmission, optical fibres have largely replaced copper wire communications in core networks in the developed world. Optical communication system use high carrier frequency (~100 THz) in the visible or near-infrared region of the electromagnetic spectrum. Because of its low loss, high capacity and bit rate it became more popular.

2.1 Optical Fibre Communication System

An optical fibre communication system has three basic components, transmitter, receiver and the transmission path as shown in the figure 2.1 [6].

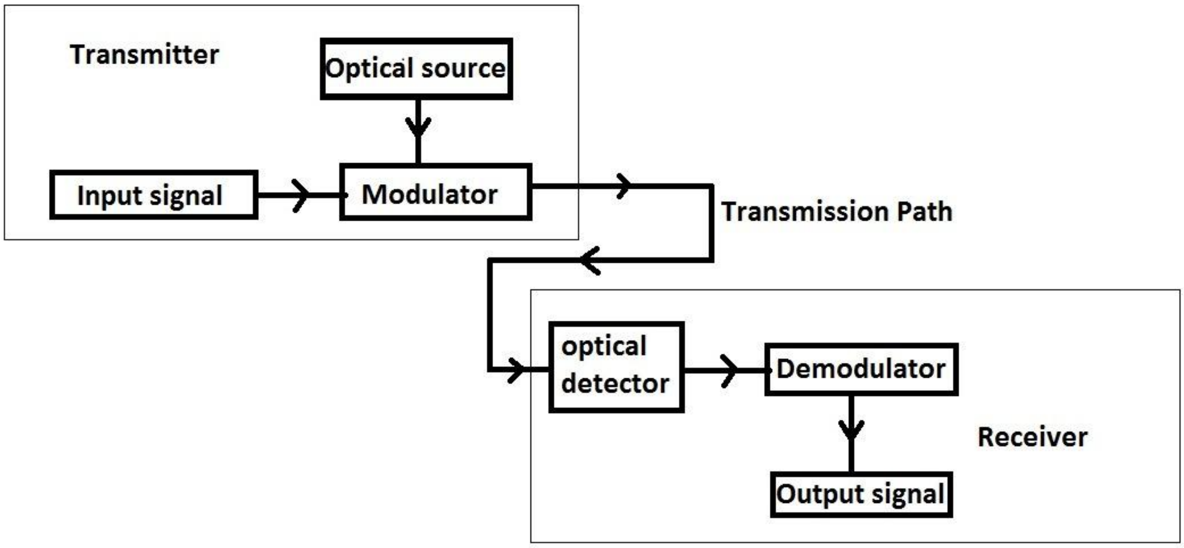

Fig 2.1 Block diagram of Optical fibre communication system

In the transmitter side the input signal is generated by a data source. The optical source is a laser source which generates optical light signal at a certain wavelength. The data source and the optical signal are fed to the modulator and then the resulting modulated pulse signal propagates through the transmission path which is an optical fibre. At the receiver side the optical signal is detected through an optical detector. The detected signal then passes through the demodulator to get the desired output signal.

An optical fibre is a flexible thin filament of silica glass that accepts electrical signals as input and converts them to optical signal. It carries the optical signal along the fibre length and re converts the optical signal to electrical signal at the receiver side.

2.2 Advantages of optical fibre communication

Optical fibres are cheap than the conventional wires.

Optical Fibre Cables are flexible and easy to install.

Optical fibres are less affected by fire.

In Optical Fibre Cables signal can propagate longer transmission distances like 50km or more (Single Mode fibre cables) without the need to regenerate the signal anywhere in-between.

The Optical fibre cables do not have speed limitations or bandwidth limitations. They can support variable speed and bandwidth depending only on optics quality used at both end.

Easily upgradable for higher speed and high bandwidth.

Optical Fibre Cables support duplex communications, bidirectional transmission from Transmitter to Receiver and vice versa.

Optical Fibre Cables do not suffer from Electromagnetic Interference as they carry light.

Optical fibres support bandwidth of up to 40Gbps to 100Gbps.

Even if many fibres run alongside each other, the chances of cross talk are very less and hence the signal loss is less compared to Copper Cables.

2.3 Wavelength Division Multiplexing

The fibre material has a large bandwidth of 30THz. If only one signal of 10MHz is used, then effectively it is the wastage of bandwidth. So to effectively use bandwidth, there are different techniques are used like Time Division Multiplexing and Frequency Division Multiplexing. But it is difficult to multiplex signal in time domain as it is very difficult to generate signal of femto seconds. So frequency division multiplexing is the best technique that can be used to multiplex signals. From this concept Wavelength Division Multiplexing Technique has evolved. Optical fibres can carry multiple light signals of different wavelength simultaneously. The technique which allows the optical fibre to carry multiple signals is called wavelength division multiplexing. So wavelength division multiplexing is the technique of sending signals of several different wavelengths of Light into the fibre simultaneously. In fibre optic communications, wavelength division Multiplexing (WDM) is a technology which multiplexes multiple optical carrier signals on a single optical fibre by using different wavelengths of Laser light to carry different signals. This helps to increase capacity and also helps bi-directional transmission over a single fibre length for transmitter and receiver.

2.4 Optical Amplifiers

When a signal travels in an optical fibre it suffers from various losses like fibre attenuation losses, fibre tap losses and fibre splice losses. Due to these losses it is difficult to detect the signal at the receiver side. So in order to transmit signal over a long distance in a fibre (more than 100km) it is necessary to compensate the losses in the fibre. Initially the optical signals were converted to electrical signal then amplified and then reconverted to optical signal. But it was a complex and costly procedure. The introduction of optical amplifiers allowed the signal amplification in optical domain. There was no need to convert the optical signal to electrical signal. So optical amplifiers revolutionized the optical fibre communication field. There are mainly two types of optical amplifiers: semiconductor optical amplifier and fibre amplifiers. Optical amplifiers were again divided into travelling wave semiconductor optical amplifier and Fabry-perot semiconductor optical amplifier. Fibre amplifiers are divided into erbium doped fibre amplifier, Raman amplifier and Brillouin amplifier.

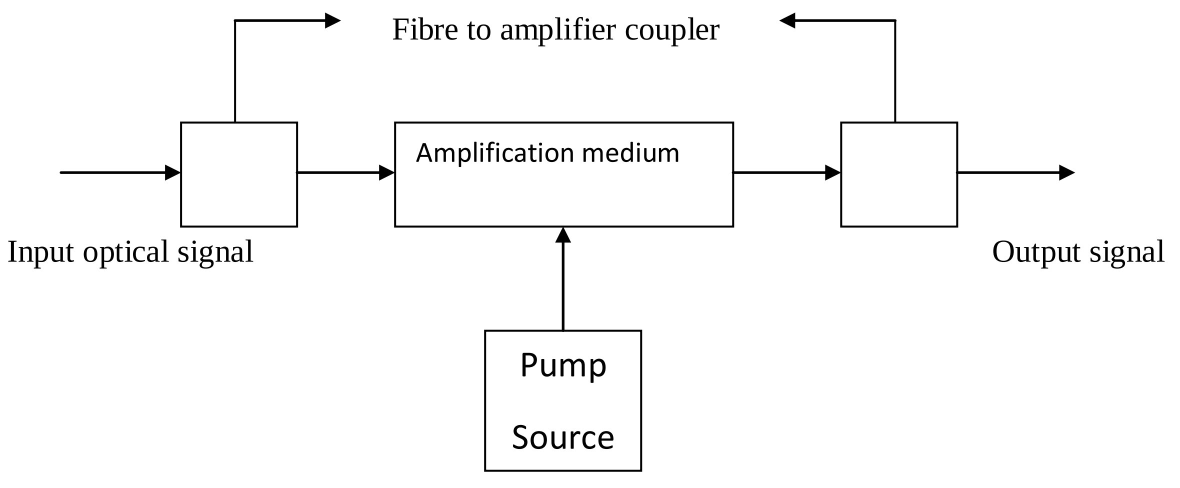

Fig 2.2 Block Diagram of basic optical amplifier

2.5 General Application of Optical amplifier

2.5.1 In-line Optical Amplifiers

In a single mode optical fiber the signal goes through loss due to attenuation. So after a certain interval of time the regeneration of the signal and its amplification needs to be done. So inline optical amplifier can be used to compensate attenuation loss and increase the distance between regenerative repeaters.

2.5.2 Preamplifier

An optical amplifier can be used as a front-end preamplifier just before an optical receiver. The weak optical signals can be amplified by the preamplifier so that the SNR degradation can be minimized, Also preamplifier shows high gain and better bandwidth.

2.5.3 Power Amplifier

Power or booster amplifiers are placed just after the transmitter to boost the signals. This helps to increase the transmission distance by 10-100 km depending on the amplifier gain and fibre loss.

The Diagram for Preamplifier, inline amplifier and post amplifier is given in fig. 2.3.

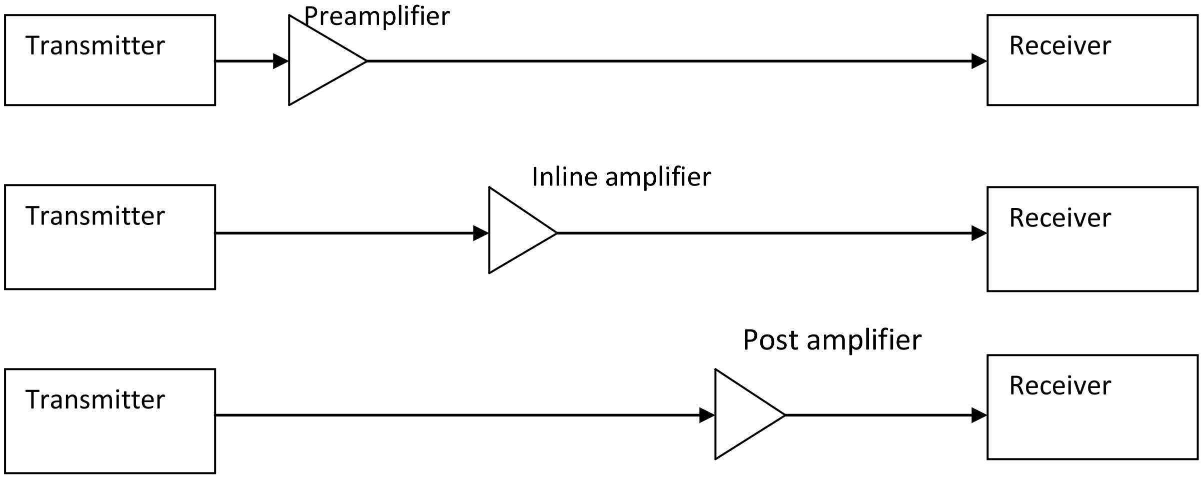

Fig 2.3 Block Diagram of different application of optical amplifier

2.6 Semiconductor Optical Amplifier (SOA)

Semiconductor optical amplifiers (SOAs) are amplifiers which use a semiconductor to provide the gain medium.

2.7 Erbium doped fibre amplifier (EDFA)

Erbium doped fibre is a conventional silica fibre heavily doped with active erbium ions as the gain medium. Erbium ions (Er^{3+}) are having the optical fluorescent properties that are suitable for the optical amplification. There are practically two wavelength widows C-Band (1530nm-1560nm) and L-Band (1560nm-1600nm). EDFA can amplify a wide wavelength range (1500nm-1600nm) simultaneously, hence is very useful in wavelength division multiplexing for amplification. EDFA basic says when an optical signal such as 1550nm wavelength signal enters the EDFA from input, the signal is combined with a 980nm or 1480nm pump laser through a wavelength division multiplexer device. The input signal and pump laser signal pass through fibre doped with erbium ions. Here the 1550nm signal is amplified through interaction with doped erbium ions. This can be well understood by the energy level diagram of Er^{3+} ions given in fig 2.3.

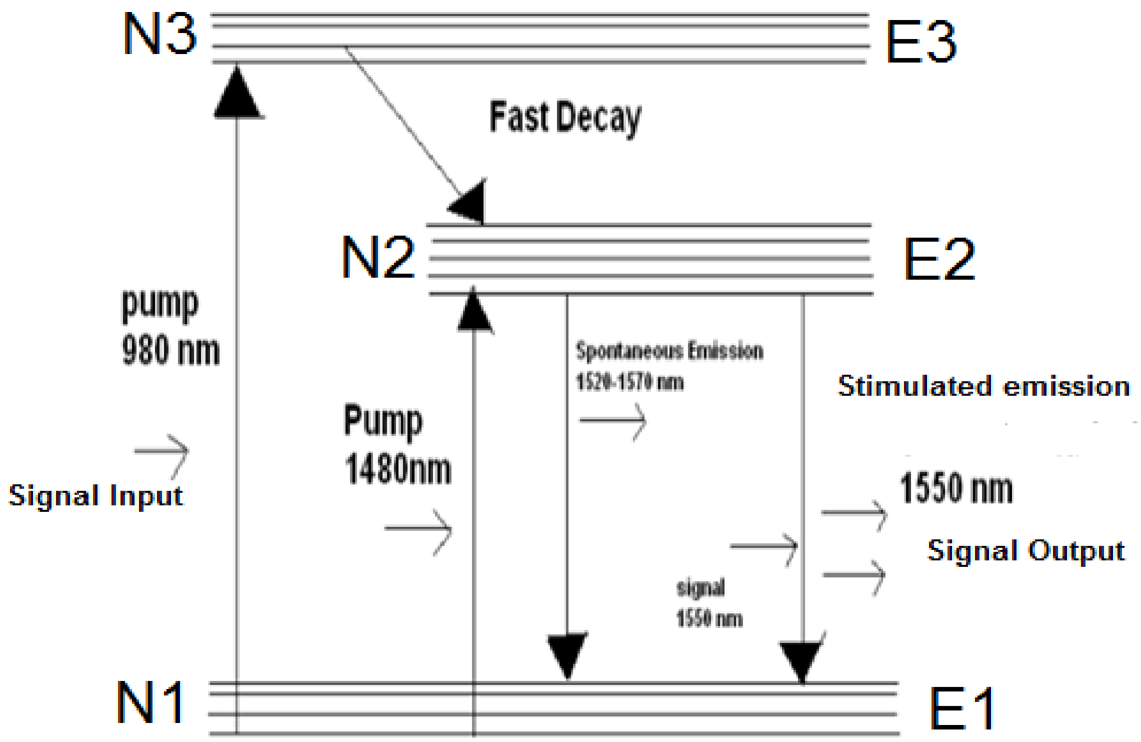

Fig 2.4 Three level energy diagram of Er^{3+} ions

The three energy levels E1, E2, E3 are the ground, meta-stable and excited state levels respectively. The population of erbium ions in the three levels are denoted by N1, N2, N3 respectively. The population density is N1>N2>N3 in equilibrium state, when no pump signal is used. When pump or signal is present the population density of levels changes with the movement of ions between the levels, through the emission or absorption of photons at frequencies determined by the energy-level difference.

As shown in the figure two pump wavelengths can be used for EDFA i.e. 980nm and 1480nm. With 980nm pumping wavelength the Er^{3+} ions in the ground state (E1) are excited to the excited state (E3). The rate of transition from ground state to the excited state depends upon the pump power. The ions in the excited state are not going to stay there for a long time and decays back to the meta-stable state and then fall back to the ground state after approximately 10ms and emits photon. This is called spontaneous emission. But photons generated in this spontaneous process are treated as noise as the photons are non-polarized and incoherent through time and space. But when the ions or photons that are in the meta-stable state incident with light photons of suitable wavelength, they fall back to the ground state emitting photons having same phase, frequency and polarization and travel in the same direction as the photons of the incident wave. This is called stimulated emission. In this process one photon gives two photons at the output. Hence multiplication of photons occurs and multiple number of photons subjected at the input generates large number of photons at the output which increases the light intensity which we call gain and it amplifies the input signal. With 1480nm the ions in the ground state excited directly to the meta-stable state and the above process occurs. When the number of ions in the excited state or meta-stable state is greater than the ions in the ground state then the population inversion mechanism occurs.

2.7.1 Basic EDFA Design

EDFA consists of length of Erbium doped fibre, Laser diode used as pump and wavelength selective coupler to multiplex or combine the signal and pump wavelength together, so that they can propagate simultaneously in the fibre. The signal and pump can both propagate in the same direction or they can propagate in the opposite direction to each other in side the EDFA. This paper briefly discusses about the types of pumping in the coming section. The length of the Erbium Doped Fibre depends upon the input signal power, pump power, Er^{3+} ion density and the signal and pump wavelength.

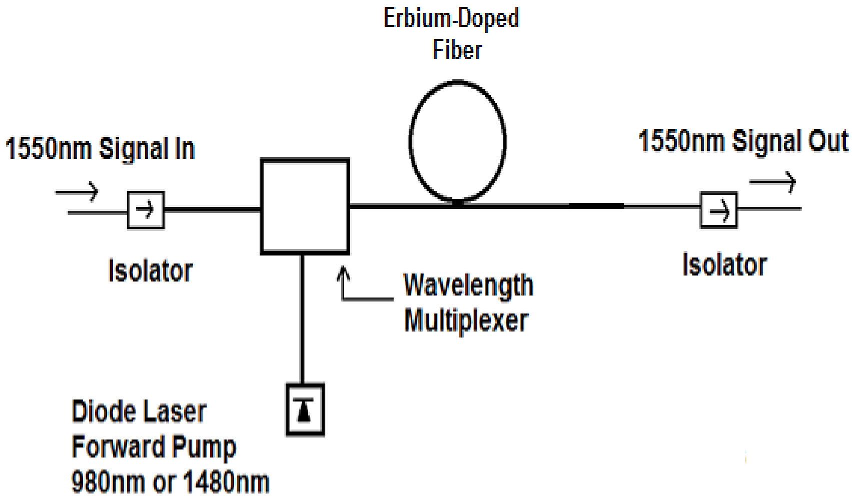

Fig 2.5 Basic Block diagram of an EDFA

In fig 2.4 a basic block diagram of EDFA amplifier co-pumped with a laser signal is shown. The input signal here is a 1550nm wavelength optical light signal. The optical signal is then combined with diode laser through a wavelength multiplexer. The combined signal is then passed through EDF where the signal interacts with the Er^{3+} ions and gets amplified. At the output we get an amplified version of the input 1550nm signal.

2.8 Raman Amplifier

Raman Amplifiers are based on the phenomena called stimulated Raman Scattering which is a nonlinear process opposite to the EDFA which is a linear effect. Raman gain arises from the transfer of power from one optical beam to another that is downshifted in frequency by the energy of an optical phonon, a vibrational mode of the medium [4]. Raman amplifiers utilize pumps to impart a transfer of energy from the pumps to the transmission signal through the Raman Effect mechanism. Raman scattering does not require population inversion as it is an elastic scattering mechanism. So it can be summarized that stimulated Raman scattering is a nonlinear optical process in which intense pump light interacts with a signal of low frequency, simultaneously amplifying the signal and producing an optical phonon. Raman scattering occurs in all optical fibres with its strength depending only on the type of optical fibre and the frequency offset and power of the interacting waves. Maximum gain occurs for a frequency offset between the pump and signal of 13.2THz.

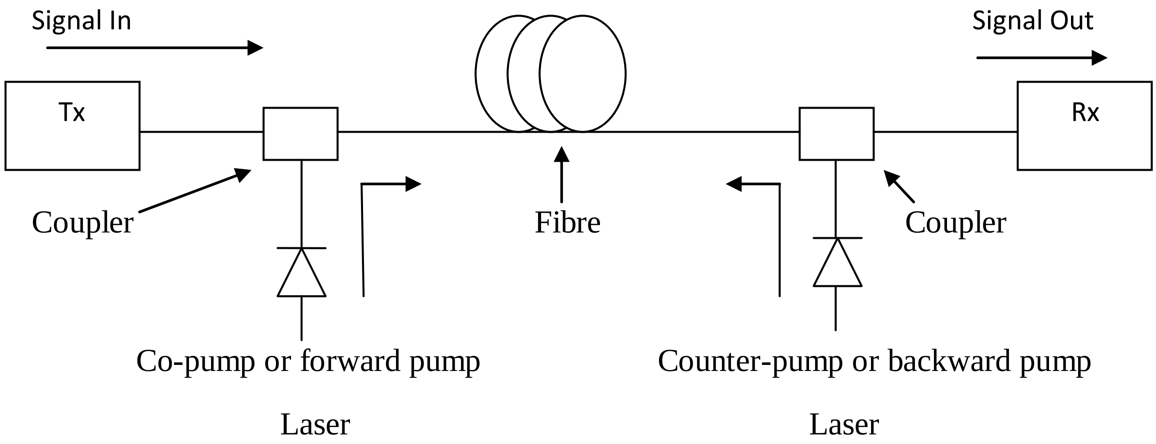

Fig 2.6 Block diagram of Raman amplifier

Optical amplifiers are needed to allow light wave communication system to expand beyond the capabilities of conventional EDFA. Raman amplifiers are excellent to serve this role as they are effective both as distributed and discrete amplifiers and can be tuned to any wavelength in the transmission window of optical fibres.

2.8.1 Distributed Raman Amplifiers

There are three main reasons of using Raman amplifiers [4]. First is to provide distributed amplification, second is the ability to provide gain at any wavelength and third is to broaden the amplification bandwidth by adding more pump wavelength. Distributed amplifiers are mainly deployed for these capabilities. In distributed amplification the fibre losses are cancelled after every short interval in the transmission fibre. It helps in increasing the signal-to-noise ratio at the output. Some of the advantages of using Distributed Raman Amplifier is upgradability [4]. There is no need to change the whole module while upgrading the current optical system. Simply by adding more pump module the existing systems the system can be upgraded with improved signal-to-noise ratio. The major benefit of using Distributed Raman Amplifier is the gain across the entire window. Raman gain spectrum is not limited to fixed energy levels as the EDFA. Raman gain can be generated at any wavelength as long as the required pump power is available. It shows better noise figure and flat bandwidth.

2.8.2 Discrete Raman Amplifiers

A Discrete Raman amplifier functions like an EDFA as an amplifying medium placed in the transmission link to provide localized gain. In Discrete Raman Amplifiers, optical fibre with high Raman gain efficiency is used to give high gain with a shorter fibre length. Particularly Dispersion compensating Fibres (DCF) are used in Discrete Raman Amplifiers.

Chapter 3

Analysis of Gain and Noise figure for EDFA with different Pumping Techniques

In this chapter we will investigate the variation of Gain and Noise figure for EDFA with different pumping techniques i.e. Forward or Co-Pumping, Backward or Counter-Pumping and Bidirectional Pumping. And also the variation of gain and noise figure is analysed for different pumping wavelength and at different pumping power.

3.1 Introduction

Erbium-doped fibre amplifier (EDFA) has played an all important role in the optical fibre communication systems. Propagation losses are the biggest concern for optical fibres. But usage of EDFA has helped immensely in compensating losses during signal propagation. For wavelength division multiplexing systems EDFAs are extremely useful because they provide uniform gain over a wide range of wavelengths. EDFAs have gain in the range of 40–50 dB. The gain depends on various parameters like doping concentration, active fibre length, pump power, core radius, erbium radius, numerical aperture, signal input power, signal bandwidth, pumping wavelength, etc. [7]. The EDFAs are pumped with laser diodes at a pumping wavelength of 980nm or 1480nm. There are different pumping techniques used for EDFAs which are explained in the next section. The EDFA gain is one of the important factor for WDM networks and also the noise figure which defines the amount of noise which is accumulated. Here in this chapter the analysis of the gain and noise figure for different pumping techniques is done.

3.2 Pumping Techniques

There are three ways to pump the Er^{3+} ions from the ground state to the upper states.

1. Forward Pumping or Co-directional Pumping
2. Backward Pumping or Counter-directional Pumping
3. Bi-directional Pumping

3.2.1 Forward Pumping

In forward pumping the input signal and the pump signal propagate in the same direction inside the fibre. The input signal and pump are combined using a pump combiner or wavelength division multiplexer. Inside the fibre the pump energy is transferred to the input signal and the signal is amplified at the output of the amplifier. Isolators are used in the scheme to make sure that the signal will travel only in one direction and no feedback of signal will occur.

3.2.2 Backward Pumping

In Backward pumping the input signal and the pump signal propagate in the opposite direction to each other inside the fibre. For amplification the direction of input and pump signal is not essential. They can travel in any direction.

3.2.3 Bidirectional Pumping

In Bi-directional pumping the input signal travels in one direction. But the there are two pump signals that travel inside the fibre. One pump signal travels in the same direction as the input signal and the other pump signal travels in the opposite direction to that of the input signal.

The different pumping configurations are shown in the figure [3.1, 3.2, 3.3].

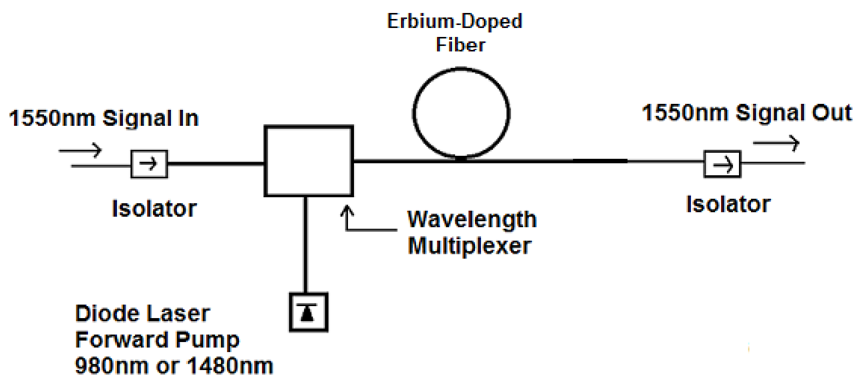

Fig 3.1 Forward Pumping or Co-directional Pumping

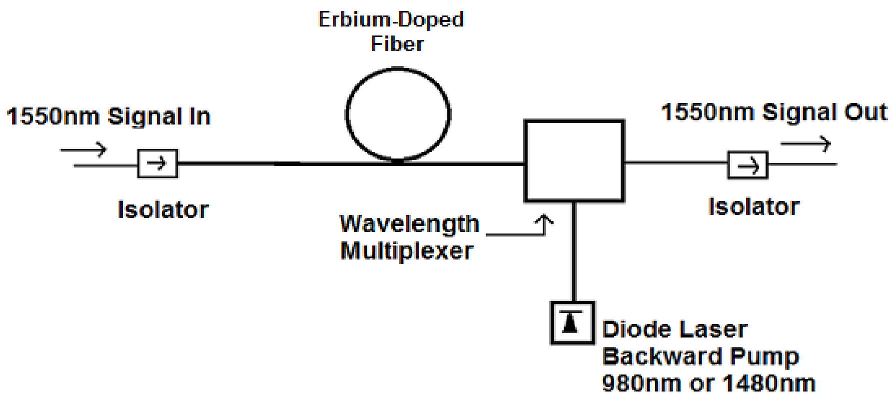

Fig 3.2 Backward Pumping or Counter-directional pumping

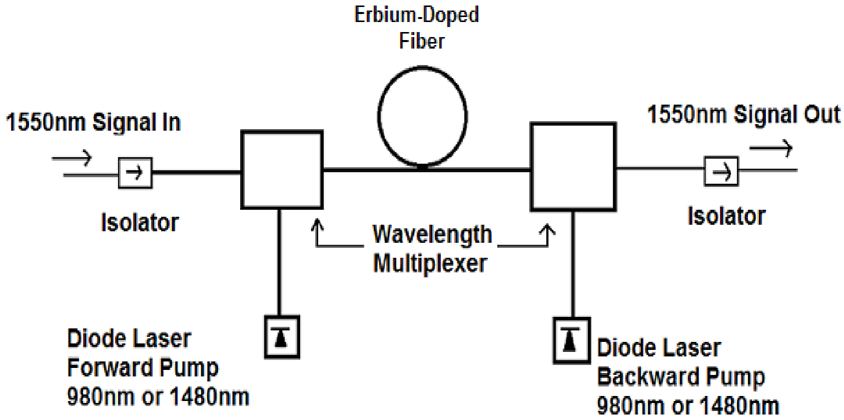

Fig 3.3 Bi-directional Pumping

3.3 Gain and Noise Figure

Gain of an erbium-doped fibre with a length of L is the ratio of the signal power at the fibre output to the signal power injected at the fibre input as:

$G = P_s(L)/P_s(0)$

Where $P_s(L)$ is the signal power at length L

And $P_s(0)$ is the signal power at the input of the EDFA.

ASE noise generated during amplification process is added to the signal leading to decrease in signal to noise ratio (SNR) at the amplifier output. SNR reduction ratio from input to output of the amplifier is defined as Noise Figure (NF), which is also used for electronic amplifiers:

$NF = (SNR)_{in} / (SNR)_{out}$

Noise Figure can also be expressed in terms of gain and spontaneous emission factor (n_{sp}) (or population inversion factor)

$NF=2 * n_{sp} * \frac{(G-1)}{G} = 2*n_{sp}$

3.5 Simulation Results

In this chapter we will analyse the gain and noise figure of the EDFA at different pumping techniques at pumping wavelength of 980nm and 1480nm. For the simulation the EDFA length is varied from 5 meter to 50 meter as required. For fig 3.4 and 3.5 the input signal is -30dBm at 1550nm wavelength. The pump power used for the simulation is 200mWatt. In fig.3.4 and 3.5, the graph is shown for variation of Gain and Noise Figure with respect to Co-pumping, Counter pumping and Bi-directional pumping.

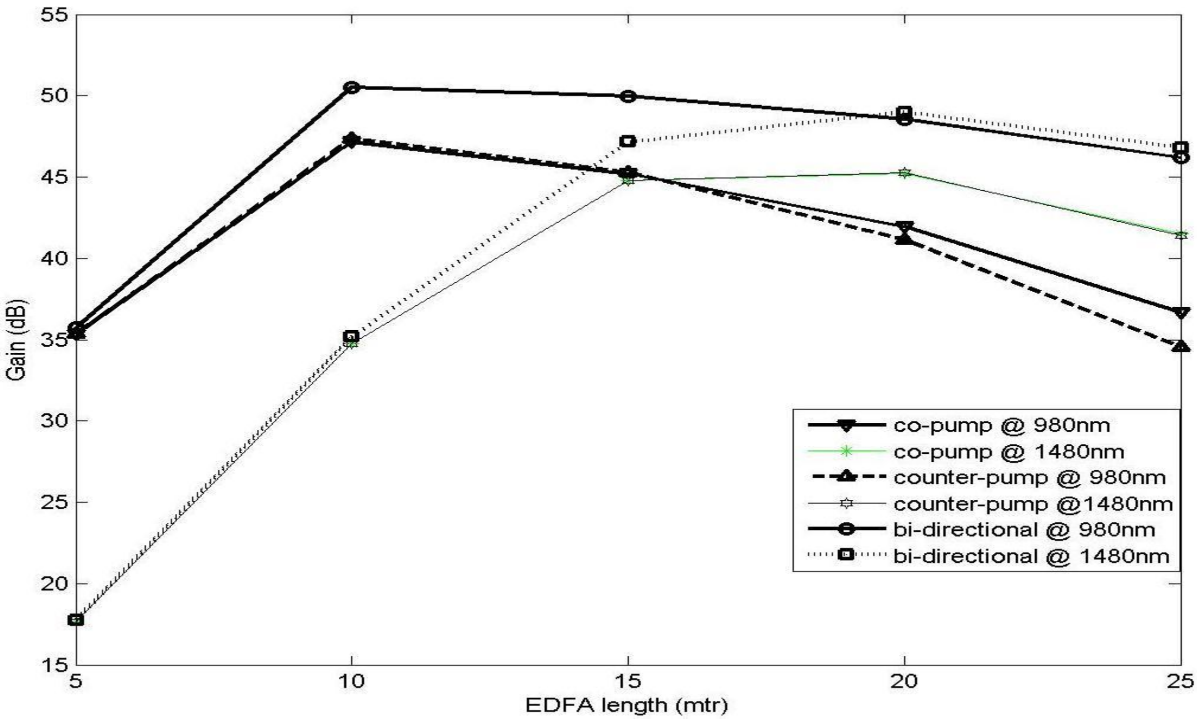

Fig 3.4 Variation of gain with EDFA length at different pumping

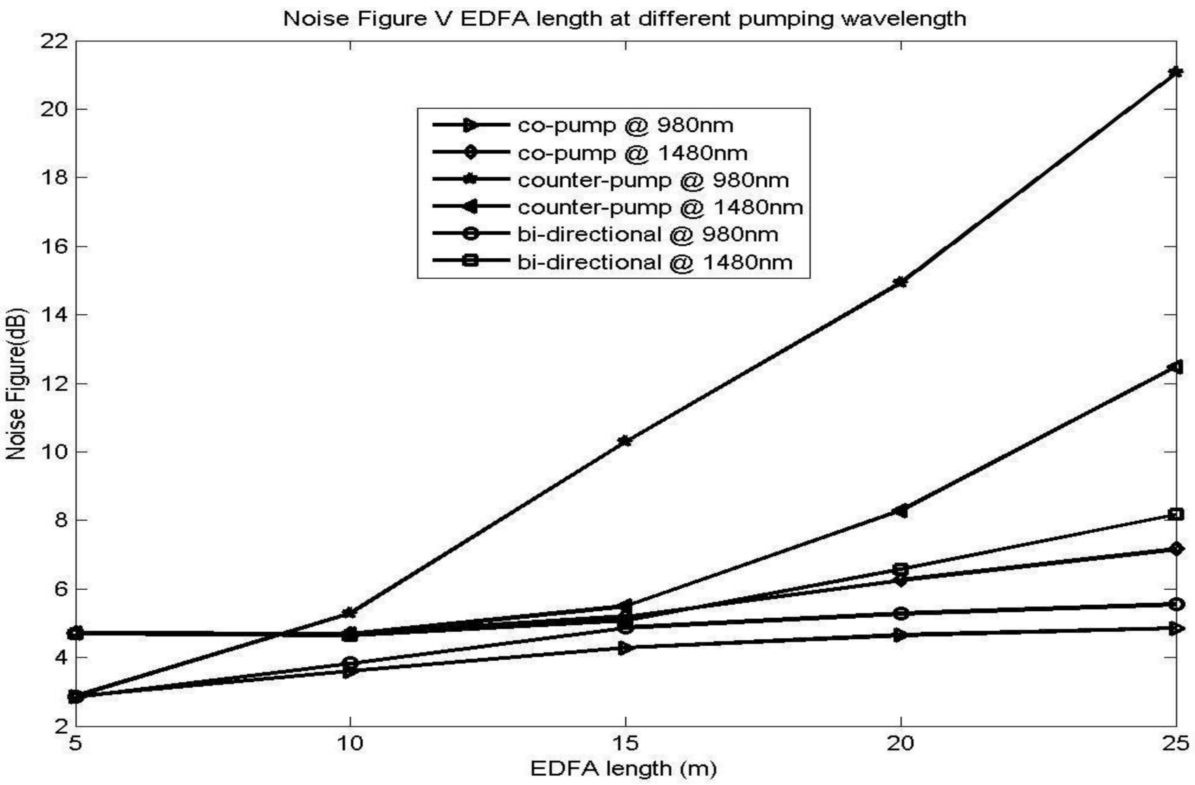

Fig 3.5 Variation of Noise Figure at different EDFA length at different pumping

From the above results in fig 3.4 and 3.5, it was observed that gain for 980nm pump is almost same for forward and backward pumping and for bi directional pumping gain is quite high. The similar case happened for 1480nm pumping wavelength. Noise figure for co-pump is the lowest at both 980nm and 1480nm pumping. For counter pumping Noise Figure is the highest among all three configurations.

In fig 3.6 the variation of gain for different pump powers is shown at 980nm for co-pumping configuration for 1535nm and 1550nm signal.

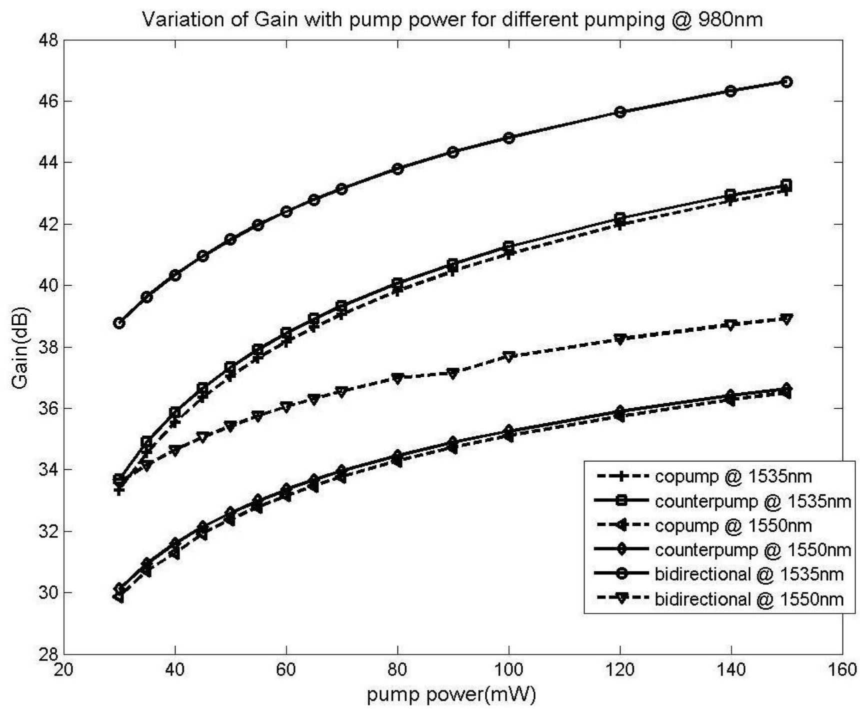

Fig 3.6 Variation of Gain with pump power for different pumping

In fig 3.6 gain for 1535nm signal is higher for counter pump than co-pump than 1550nm signal, because the 1535nm signal has higher cross section than 1550nm signal.

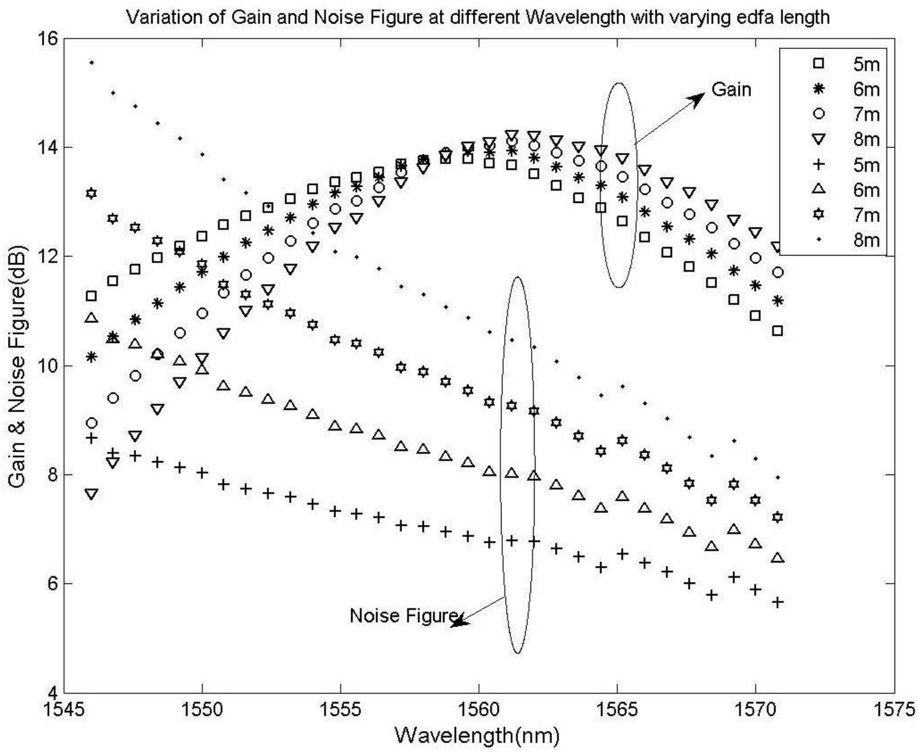

Fig 3.7 variation of gain and noise figure for varying EDFA length

In fig 3.7 the variation of gain and noise figure for different EDFA length is shown for a 32-channel transmitter. Here we can observe that for smaller wavelength the gain is low and it increases with the higher wavelength and again falls down.

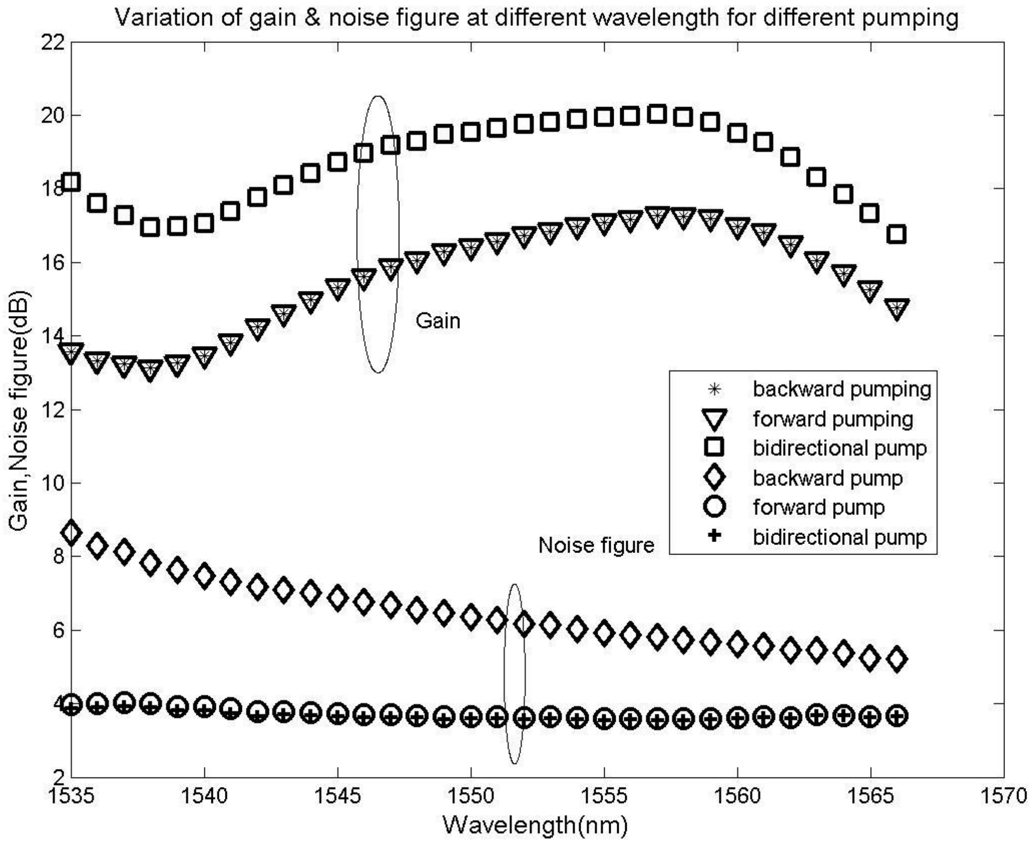

Fig 3.8 Variation of gain and noise figure for 32-channel for different pumping

In fig 3.8 for a 32 channel transmitter the variation of gain and noise figure is shown. For forward and backward pumping gain is almost same and for bi-directional pumping the gain is high. Noise Figure for Counter pumping is high than the other pumping techniques. Noise figure for bidirectional pumping and co-pumping is same.

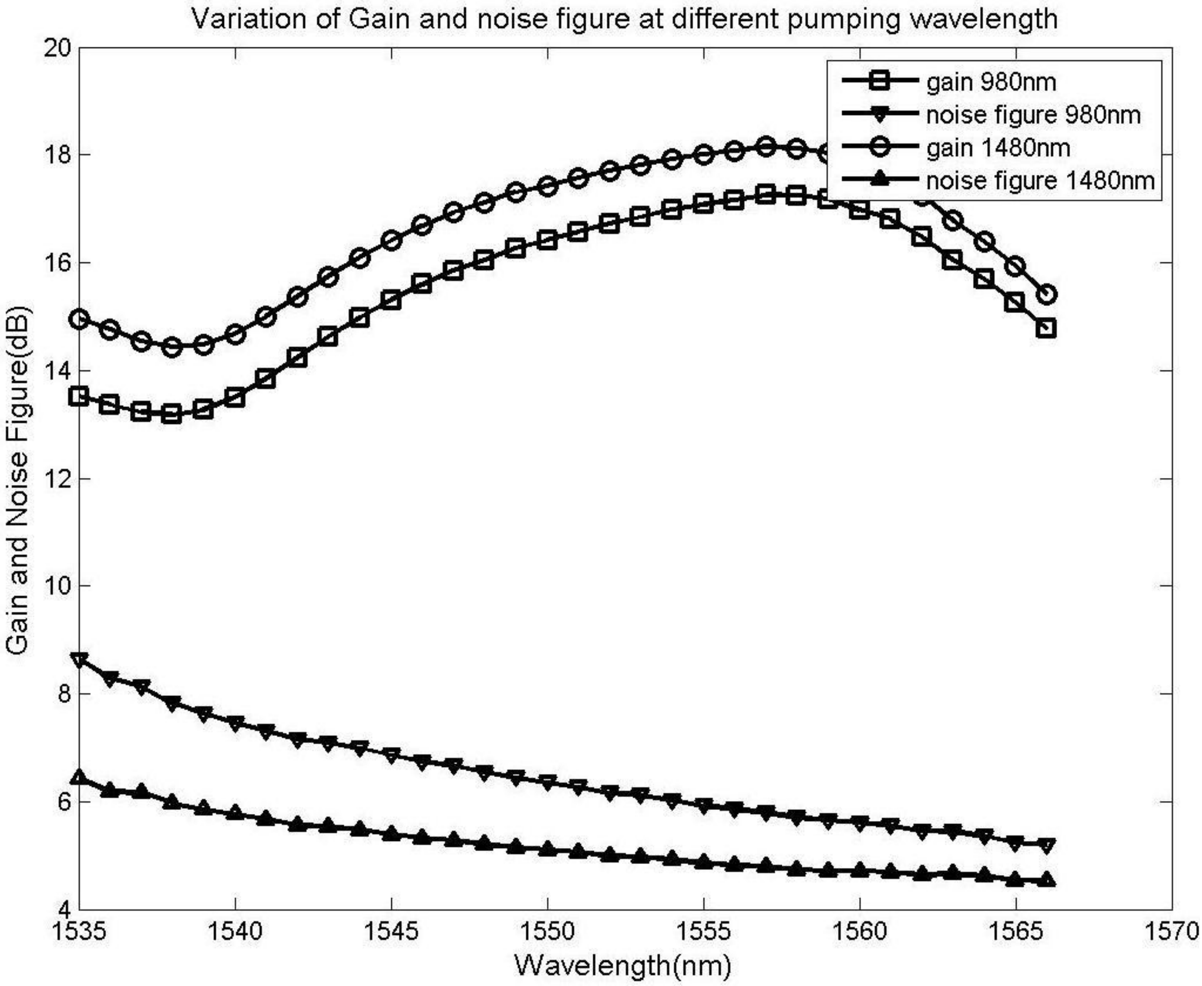

Fig 3.9 Variation of Gain and noise figure at different pumping wavelength

In fig 3.9 the variation of gain and noise figure for different pumping wavelength is shown. Here backward pumping is used for 32 channel WDM network. The input power per channel is -10dBm. EDFA length is 5m, pumping power is 200mWatt. The wavelength range is 1535nm to 1566nm with 1nm wavelength spacing. It was observed that gain for 1480nm is higher than 980nm and noise figure at 1480nm is less than 980nm pumping wavelength.

3.6 Conclusion and Future Work

Here in this chapter the variation of Gain and Noise figure was observed with different pumping techniques. The co-pumping technique was found to be the most preferred technique because of its low noise figure. And bidirectional pumping is the most suitable for high gain and low noise figure. Counter pumping configuration shows high gain but high noise figure also. So if good noise figure is the requirement then co-pumping is the best scheme. For high gain and low noise figure bidirectional pumping is the most suitable. If only gain is required then counter pumping scheme can be applied.

Chapter 4

Effect of Dispersion Compensating Fibres

In this chapter we will investigate the effects of DCF in optical fibre network. Here we will analyse the Quality factor, Bit Error Rate, Output Power for different length of DCF and SMF with the assumed set of dispersion values for both DCF and SMF. Comparison of different configuration is analysed and best configuration is observed.

The effect of DCF is compared for different data rates i.e. 10Gbps and 40Gbps for 8-channels, 16-channels optical network. Here we will compare the Q-Factor and bit error rate for different data rates as mentioned above.

4.1 Introduction

In optical fibre different colours of light travels at different speed. Even though they start from the same point, but they reach the destination at different time. This time delay is called chromatic dispersion. This dispersion occurs due to different colour of light and different wavelength of light. This chromatic dispersion causes pulse broadening at the output. At the input a perfect light pulse enters into the fibre. But after travelling a certain fibre length the light pulse gets wider. This is due to chromatic dispersion. When multiple light pulses travel inside the fibre the light pulses get wider and overlap with each other at the output end of the fibre. Hence it becomes difficult to detect the signals individually at the output. This dispersion also causes Bit error rate. Chromatic dispersion is sum of two different types of dispersion. These are Material dispersion and Waveguide dispersion. The refractive index of silica is frequency dependent. Different frequency components of light which means different wavelength of light travels at different speed in silica fibre. Material dispersion depends upon the refractive index of the material, and we cannot change it. The second type of dispersion is called waveguide dispersion. The light pulse travels partly in core and partly in cladding. Light travels faster at the core and slower at the cladding. The overall speed and the power which is distributed in the fibre vary. Hence it causes dispersion. The detection of pulses becomes even more difficult for fibre systems with high data rate for example 40Gbps systems and above. Therefore it is essential to compensate the dispersion of the signal before its detection for error free transmission.

So to compensate this dispersion losses there should be some device installed in the WDM network. One of the common methods used is deploying Dispersion Compensating Fibres (DCF) within a network to compensate dispersion. DCF has negative dispersion and negative slope and its value is approximately five to ten times that for single mode fibre. The dispersion value for DCF component is chosen in such a way that it will compensate the loss occurred due to SMF transmission span. The SMF in a fibre

4.2 Simulation Model

To investigate the effect of dispersion on the 8-channel and 16-channel WDM system at the speed of 10Gbps and 40Gbps the following model is used as shown in fig. 4.1.

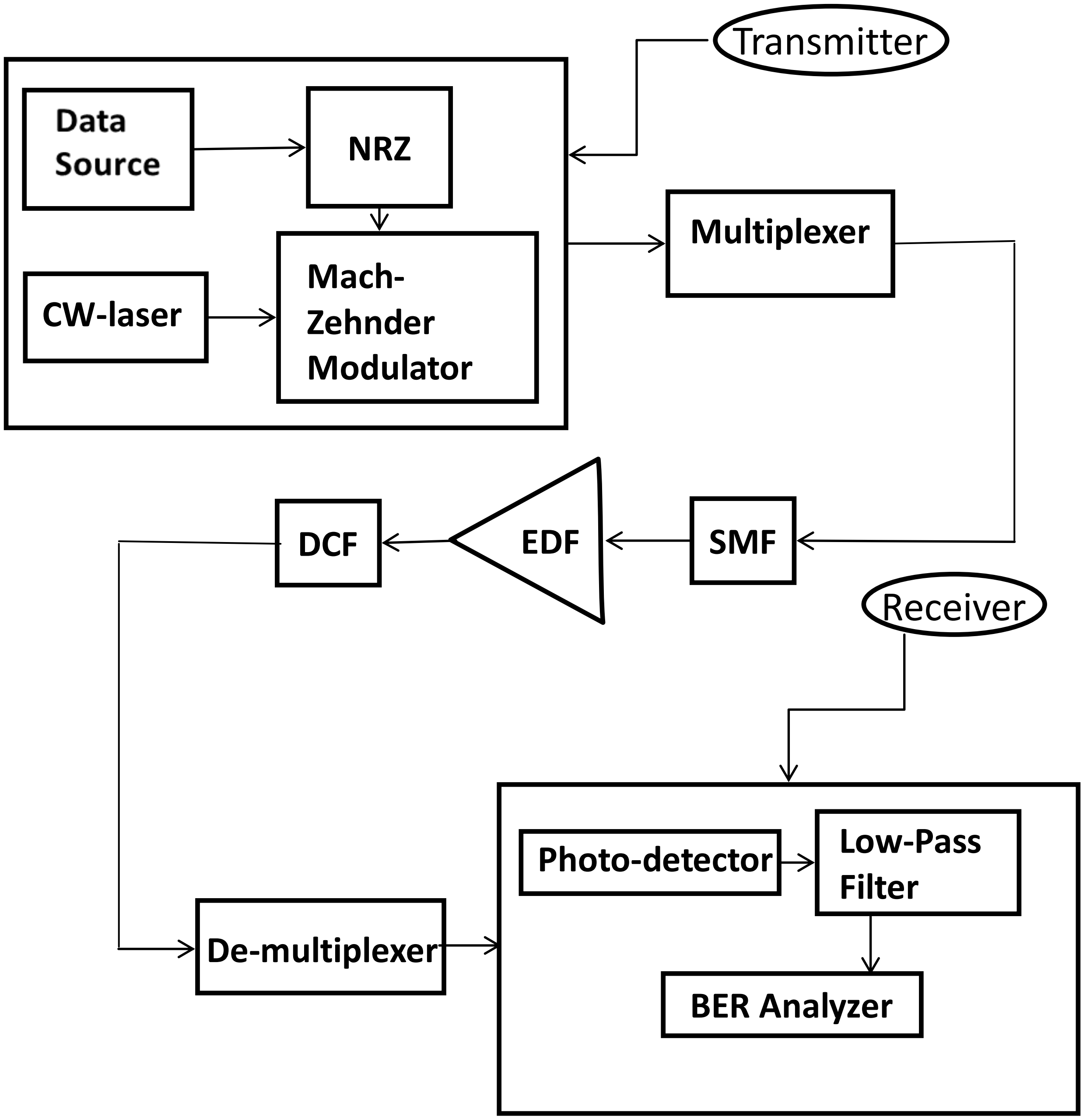

Fig. 4.1 Block Diagram for the simulation model

The transmitter section consists of data source, Laser source and Mach-Zehnder modulator. The data source is then converted to Non-Return to Zero (NRZ) format. The Data source and laser signal are fed to the Mach-Zehnder modulator, where the inputs generated from data source are modulated with the laser signal are transmitted. The output from the modulator is now an optical signal with certain wavelength. When multiple optical signals are transmitted in a fibre they are multiplexed with wavelength division multiplexer. The multiplexed signal is then passed through the SMF fibre, then through the optical amplifier (EDFA) and then through the DCF fibre to the detector. In the detector section the de-multiplexer is used to get the different optical signals with different wavelengths which were multiplexed at the transmitter side. The Receiver side consists of photo-detector, low-pass filter and the BER analyser. The photo-detector detects the optical signal and then the signal is passed through a low pass filter. The BER analyser is used to check the Bit Error rate and the Q-factor of each signal.

4.3 Simulation Parameters

EDFA parameters used in the simulation given in table no 4.1

Length(m)	5
Reference wavelength(nm)	1550
Pumping wavelength(nm)	980
Pumping power(mW)	50
Pumping Technique	Forward

Table no. 4.1

The parameters taken for the SMF and DCF fibres are given in the table. no 4.2

Fiber Parameters	SMF	DCF
Length(Km)	50	10
Dispersion(ps/km/nm)	16.12 to 18.60	-80.12 to -83.84
Loss(dB/km)	0.2	0.5
Sequence Length(Bits)	128	
Samples per bit	64	
Bit rate(Gbps)	10,40	

Table no. 4.2

4.4 Results and Discussions

In this chapter the variation of Q-factor and Bit error rate with respect to the system length is analysed. This simulation is done for 8-channel and 16-channel transmitter at 10Gbps and 40Gbps data rate. The wavelength range for the 8-channel transmitter is 1546nm to 1551.6nm with the wavelength spacing of 0.8nm between channels. The wavelength range for the 16-channel transmitter is 1546nm to 1558nm with the wavelength spacing of 0.8nm between channels. The input power per channel is -10dBm. The SMF length is taken as 50Km and DCF length is 10Km. The EDF is placed between the SMF and DCF. EDF length is 5m and is forward pumped at 980nm with 50mwatt pump power.

In fig. 4.2 the variation of Q-factor with system length for 8-channel transmitter is shown. The system length is varied from 100Km to 2000Km and the Q-Factor for 1546nm and 1550nm channel at 10Gbps and 40Gbps is observed.

Similarly in fig. 4.3 the variation of Q-factor with system length for 16-channel transmitter is shown. The system length is varied from 100Km to 1000Km. The Q-factor 1546nm and 1550nm channel at 10Gbps and 40Gbps is observed.

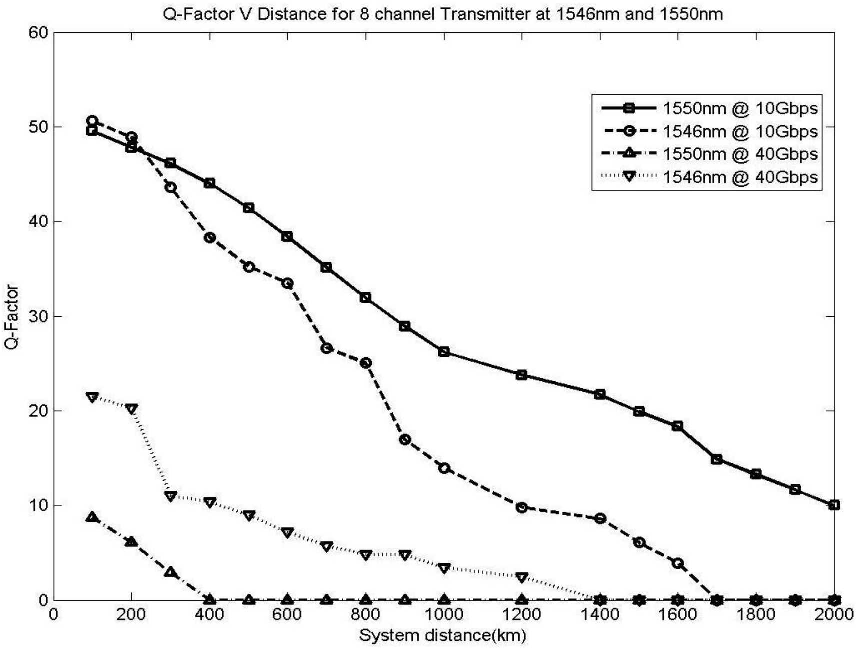

Fig 4.2 variation of Q-factor with system length for 8 channel transmitter

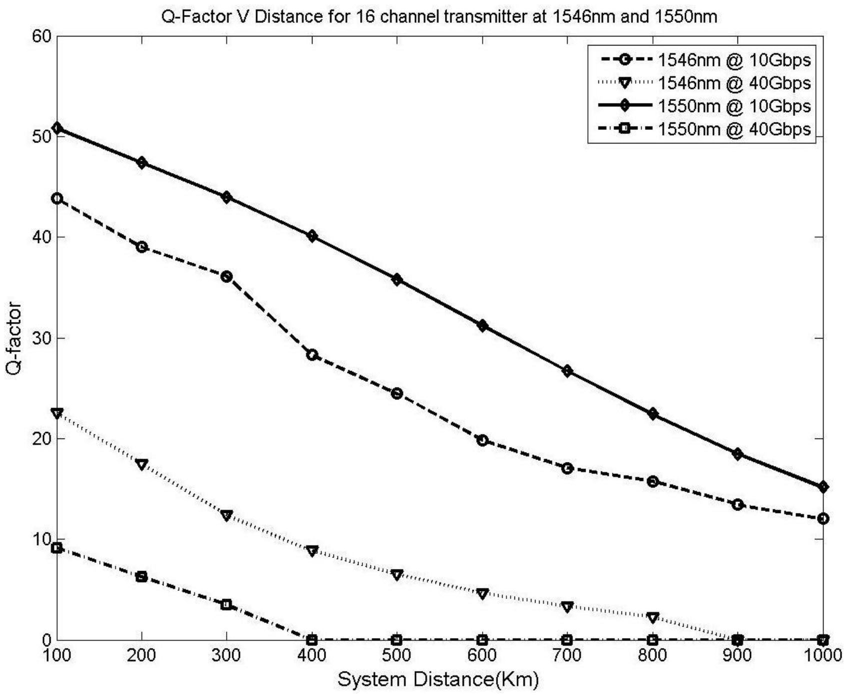

Fig 4.3 Variation of Q-factor with system length for 16 channel transmitter

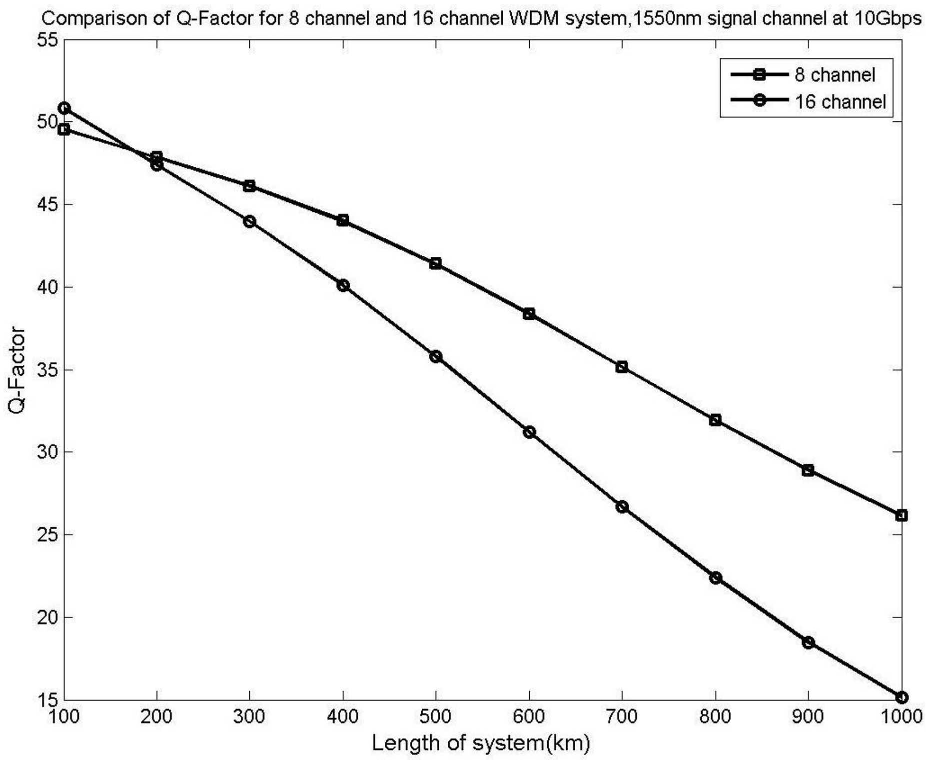

Fig 4.4 Comparison between 8-channel and 16-channel at 10Gbps

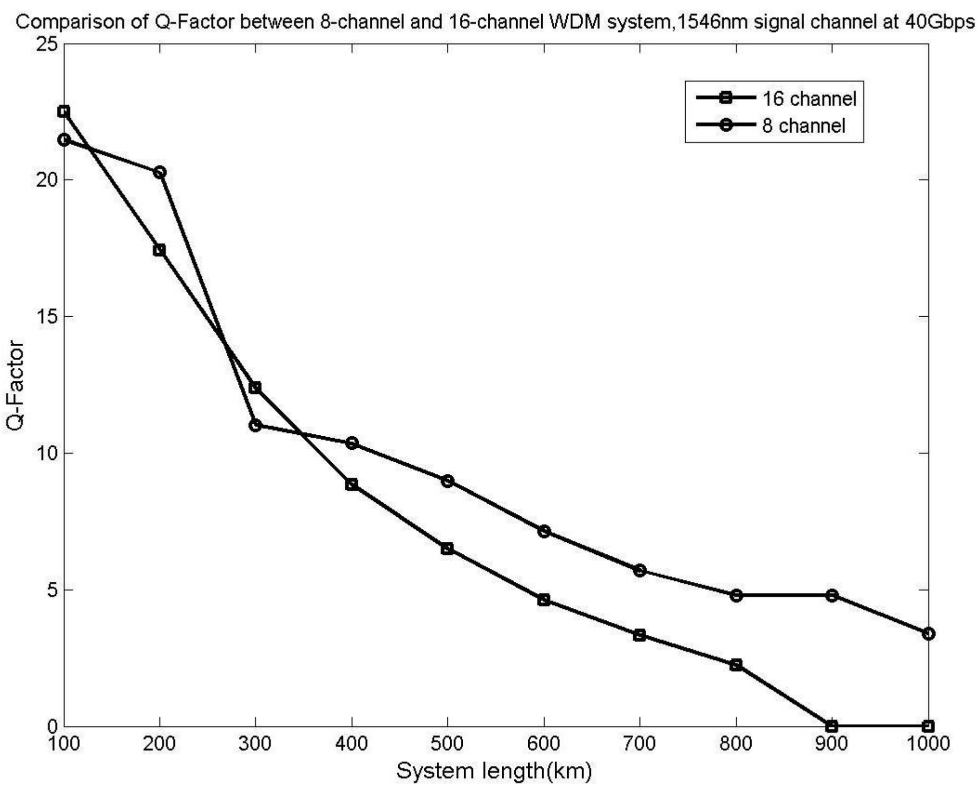

Fig 4.5 Comparison between 8-channel and 16-channel at 40Gbps

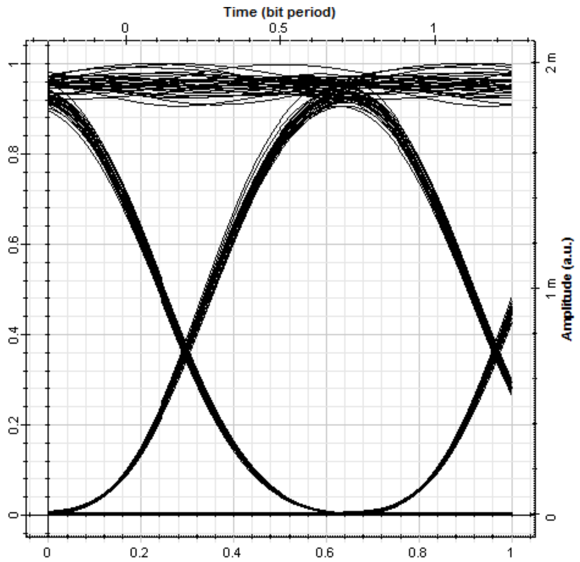

Fig 4.6 (a) 8-channels, 1546nm, 100km

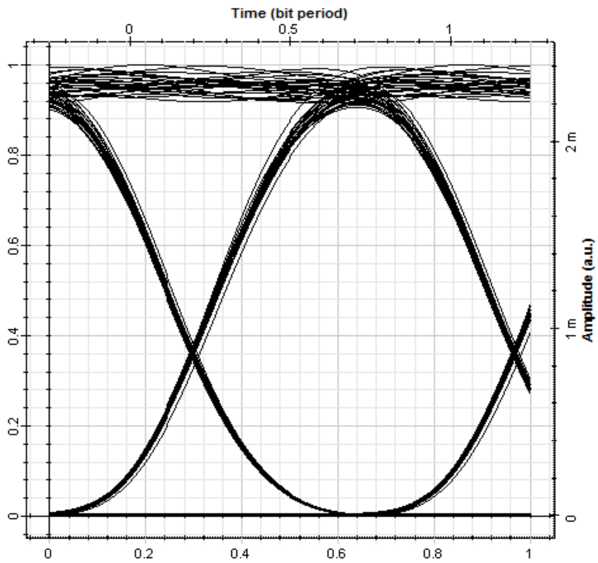

Fig 4.6 (b) 8-channels, 1550nm, 100km

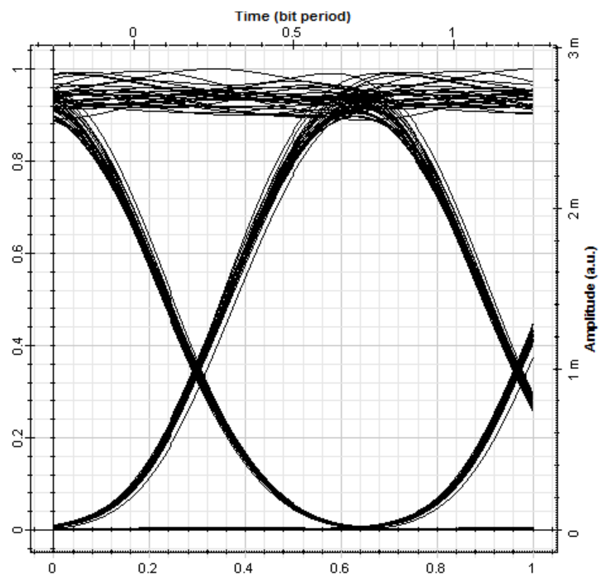

Fig 4.6 (c) 8-channels, 1546nm, 500km

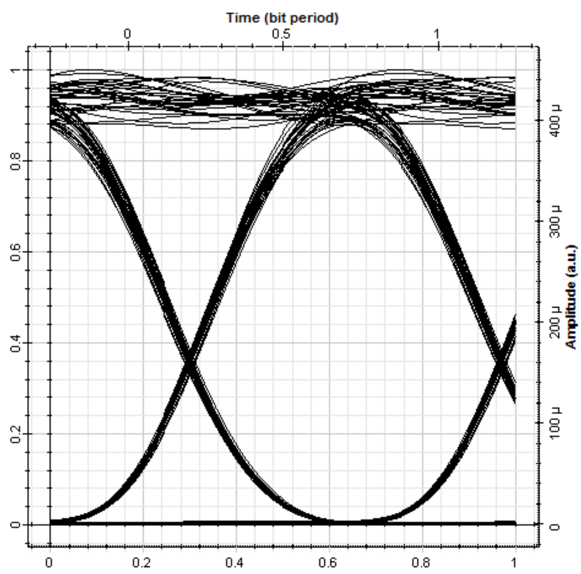

Fig 4.6 (d) 8-channels, 1550nm, 500km

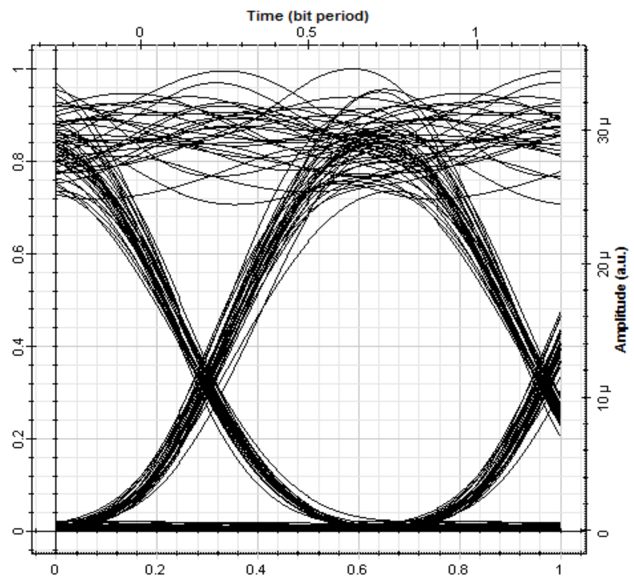

Fig 4.6 (e) 8-channels, 1546nm, 1000km

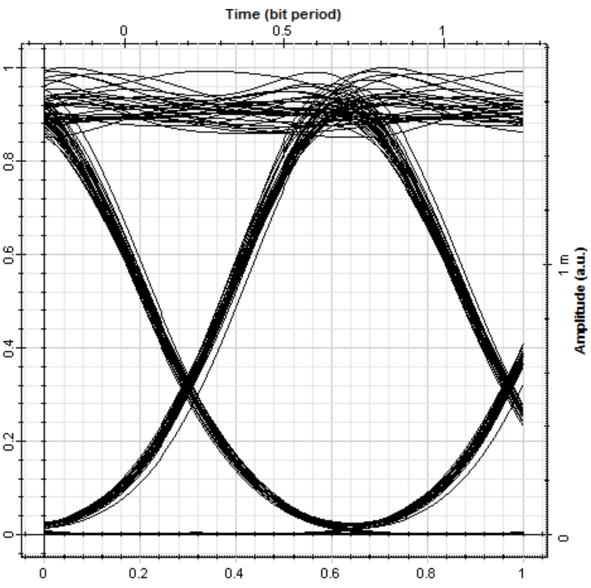

Fig 4.6 (f) 8-channels, 1550nm, 1000km

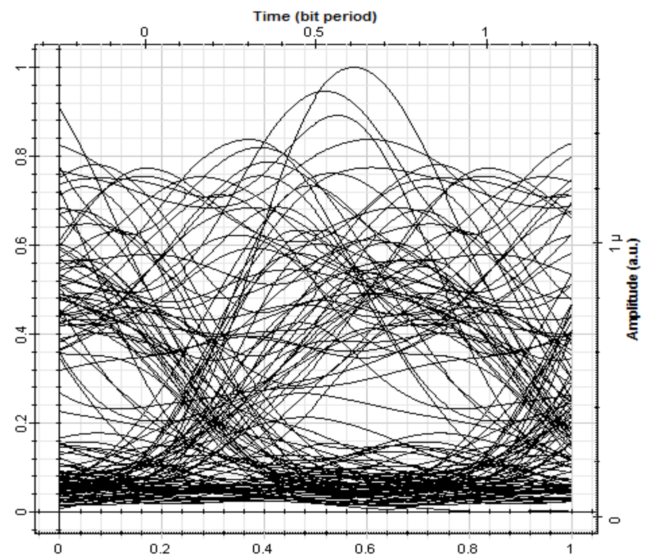

Fig 4.6 (f) 8-channels, 1546nm, 1500km

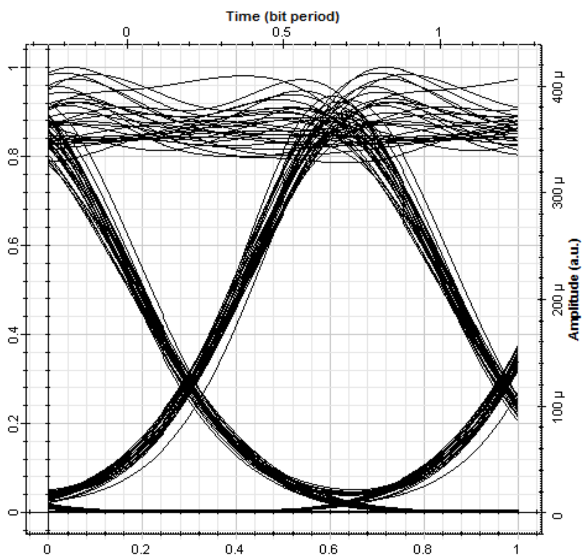

Fig 4.6 (g) 8-channels, 1550nm, 1500km

Fig 4.6 (a) to 4.6 (g) shows the eye height for the 8-channel transmitter for different system length at 10Gbps.

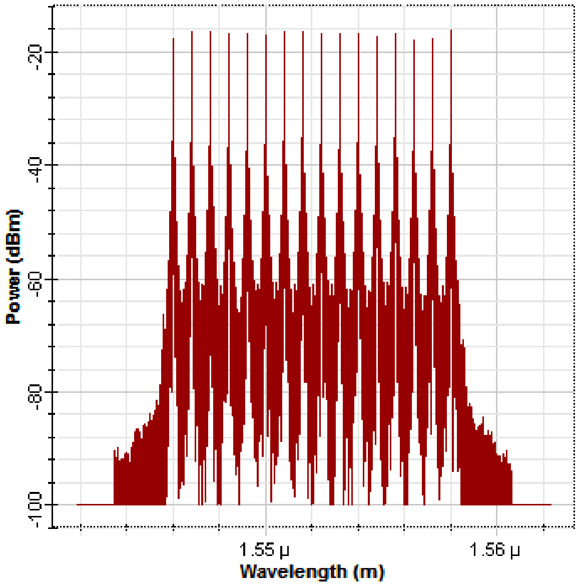

Fig 4.7 (a)

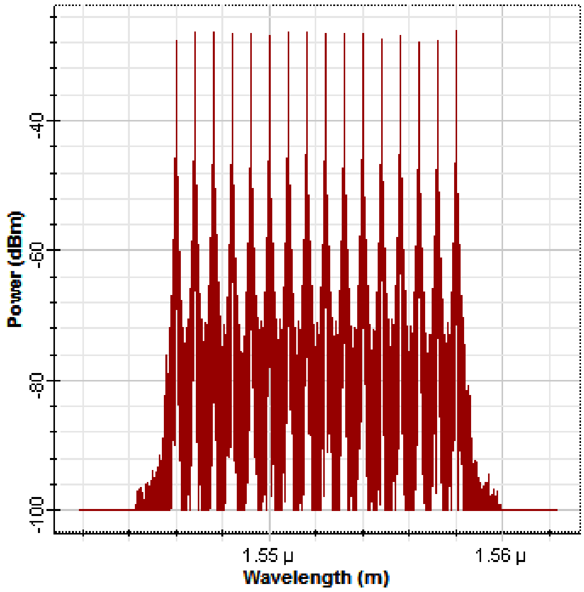

Fig 4.7 (b)

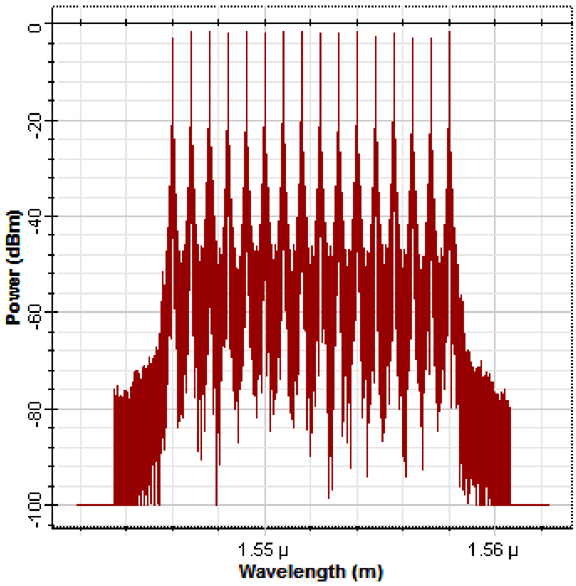

Fig 4.7 (c)

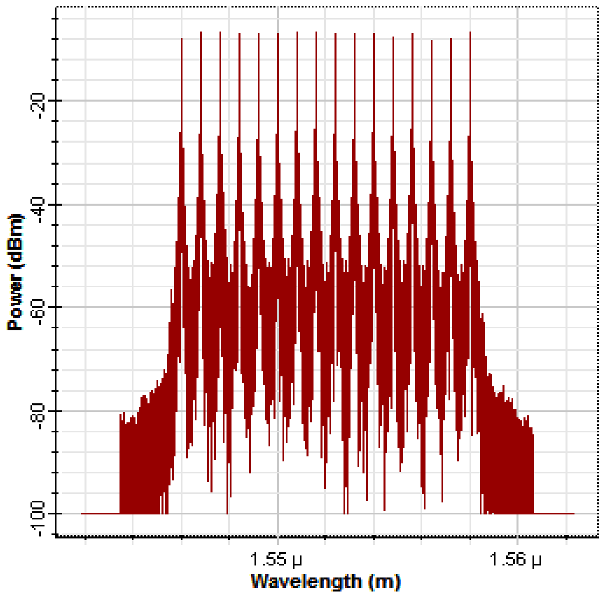

Fig 4.7 (d)

Fig 4.7 (a) shows the input signal spectrum, Fig 4.7 (b) shows the spectrum after SMF after 400km distance, Fig 4.7 (c) shows the spectrum after the EDFA, Fig 4.7 (d) shows the spectrum after DCF.

Here in fig 4.2 it can be seen that for 8 channel transmitter the Q-Factor for 1550nm signal at 100km is 49.53 and at 2000km is 9.99624 at 10Gbps. So the Q-Factor is very much acceptable for this system for a 2000km distance optical network. The observed Q-factor for 8 channel transmitter for 1546nm at 100km is 50.60 and at 1600km is 3.914. Beyond 1600km distance the Q-factor is 0. This Q-factor is good till 1600km but is not suitable beyond 1600km distance.

When the same observation was done for 40Gbps data rate network, for 1550nm signal the Q- factor at 100km distance is 8.71 and at 300km distance it is found to be 2.99. Hence it can be observed that for the current system is not suitable for 40Gbps data rate for 1550nm signal. For 1546nm signal at 100km distance Q-Factor is 21.46 and at 700km Q-factor is 7.14 which is acceptable. So this system is good for signal detection up to 700km distance.

The same observation was done for 16 channel transmitter. In fig 4.3 it is found that for 10Gbps data rate and 1546nm signal, Q-factor at 100km is 42.97 and at 1000km is 9.65. For 1550nm signal Q-factor at 100km is 50.80 and at 1000km is 15.15. For 40Gbps data rate and 1546nm the Q-factor at 100km is 22.49 and at 500km is 6.50. For 1550nm signal at 40Gbps Q-factor is 9.15 at 100km and 6.27 at 200km system distance.

In this chapter the final work that is done is comparing the systems at different SMF and DCF length. For the simulation an 8-channel transmitter was observed at 10Gbps data rate. The input power per channel is -10dBm. The different configurations are 50km SMF and 10km DCF, 25km SMF and 5km DCF and 75km SMF and 15km DCF system. The Q-factor for the three configurations is done in fig. 4.6.

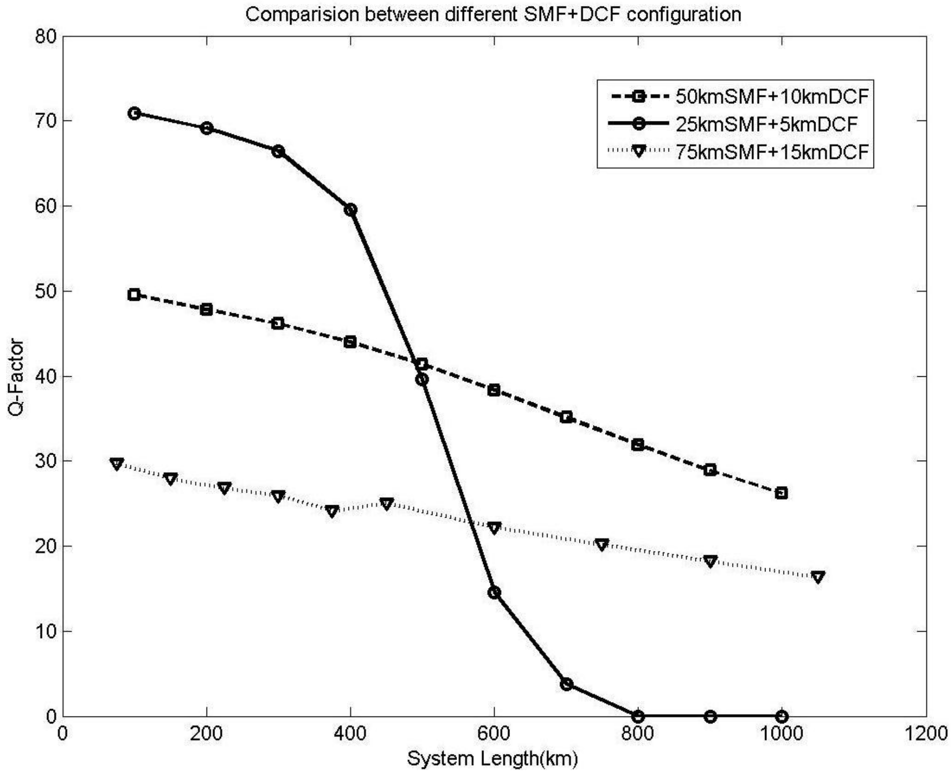

Fig 4.8 Comparison between the three configurations

In fig 4.6 Q-factor for the above three configurations is compared for 1550nm signal wavelength. For 50km SMF + 10km DCF, Q-factor is 49.53 at 100km and 26.16 at 1000km. For 25km SMF + 5km DCF, Q-Factor is 70.94 at 100km and 3.79 at 700km. For 75km SMF + 15km DCF, it is found to be 29.74 at 75km and 16.36 at 1050km. From the above comparison we observed that 25km SMF + 5km DCF configuration shows highest Q-Factor at 100km but is zero at 800km. So it is not suitable for longer transmission length. The 50km SMF + 10km DCF configuration shows the best result and hence can be preferred over the other two configurations.

4.5 Conclusion and Future Work

Here in this chapter the effect due to dispersion and its compensation is studied. The DCF was used to compensate the dispersion loss. The Q-Factor for 8-channel and 16-channel was compared at a data rate of 10Gbps and 40Gbps. It was found that Q-Factor for 8- channel is greater than 16-channel. For 10Gbps data rate Q-Factor is high compared to 40Gbps. The comparison of different configurations with different SMF length and DCF length was done. And it was found that configuration having 50km SMF length and 10km DCF length shows the better Q-factor for a longer transmission length. For higher data rates like 40Gbps the pulse broadening is more. Hence it suffers from more dispersion losses. For longer transmission length the effects due to polarization mode dispersion needs to be compensated. Further work can be done to improve the Q-factor of 40Gbps data rate network.

Chapter 5

Conclusion and Future work

In the third chapter the variation of Gain and Noise figure was observed with different pumping techniques. The co-pumping technique was found to be the most preferred technique because of its low noise figure. And bidirectional pumping is the most suitable for high gain and low noise figure. The counter pumping technique shows the highest gain and the worst noise figure. One can work on pumping power and pumping wavelength for higher gain and low noise figure.

In the fourth chapter the effect due to dispersion and its compensation is studied. The DCF was used to compensate the dispersion loss. The Q-Factor for 8-channel and 16-channel was compared at a data rate of 10Gbps and 40Gbps. It was found that Q-Factor for 8- channel is greater than 16-channel. For 10Gbps data rate Q-Factor is high compared to 40Gbps. Further work can be done to improve the Q-factor 40Gbps network.

This analysis can be implemented in a WDM network for better transmission in the presence of lossy components. Suitable EDFAs with different pumping techniques can be deployed to compensate the attenuation loss. DCFs can be installed in the WDM network for longer transmission with minimum dispersion.

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